The Effects of Soil Parameters on the Growth and Survival of Chestnut

Honor's Thesis

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INTRODUCTION

American chestnut [*Castanea dentata* Marsh. (Borkh.)] was an important tree species, ecologically and economically, in the eastern North American forest until it was essentially extirpated in the early 20th century by chestnut blight, caused by *Cryphonectria parasitica* (Murr.) Bar. (Russell 1987, McCament and McCarthy 2005, Jacobs 2007). This canker disease is lethal to the above-ground tree, but typically does not kill the root system. The few surviving chestnut are usually stump-sprouts from the trees that once comprised more than 50% of the basal area in many northeastern forests (Anagnostakis 1987, Braun 1950).

The American Chestnut Foundation (TACF), has been working since the 1980s to breed a blight-resistant, hybrid chestnut through a backcross breeding program utilizing American chestnut and Chinese chestnut (*Castanea mollissima* Blume) (Burnham et al. 1986, Hebard 2001). These hybrids, which resemble American chestnut in ways such as growth habit and morphology but incorporate the Chinese chestnut genetic blight resistance, are now being produced under the name of 'Restoration Chestnut,' and it is in the interest of TACF to explore reintroduction of these trees into the forest (Diskin et al. 2006, Hebard 2006).

For successful reintroduction of this keystone species, more information is needed on optimal site conditions for successful chestnut establishment and growth (Jacobs 2007, Rhoades 2006, McCament and McCarthy 2005). TACF's program is the first-ever attempt to save a tree species through a breeding program and, if successful, could provide a valuable paradigm for other tree species threatened by exotic pests or pathogens.

In 2004, the Appalachian Regional Reforestation Initiative (ARRI) was founded as a collaboration between environmental groups, the coal industry, academic institutions, citizen groups, and agencies to restore coal-mined lands using the Forestry Restoration Approach (FRA), to achieve goals under the Surface Mining Control and Reclamation Act (SMRCA; Angel et al. 2005). Much of the reclaimed strip-mine land in Appalachia remains in grasslands because factors such as alkaline, compacted soils and competitive grass species impede re-establishment of forests. Forests were the predominant pre-mining vegetation of much of Appalachia's present strip-mined areas, and are more beneficial both ecologically and economically than the hay and pasture land that has been the post-mining status quo (Rodrigue and Burger 2004, McCarthy et al. 2008). American chestnut has been found to thrive on abandoned mine land, which provides a great opportunity for the restoration of both the land and the forest (McCarthy et al. 2008). ARRI's forestry reclamation approach includes creating soil conditions that are conducive to tree growth; therefore, it is important to know what soil microenvironments are most suitable for growth of chestnut.

With seedlings available from TACF's breeding program, and the synergy of uniting chestnut planting with ARRI's mission of reclamation of coal-mined lands, research is needed to examine the effectiveness of the establishment of chestnut, including the Restoration Chestnut, on reclaimed mine lands. Effective methods should result in high survival and rapid growth rates. Since chestnut is very sensitive to soil conditions (McCament and McCarthy 2005), identifying optimal, as well as detrimental, soil conditions for survival and growth is crucial for successful chestnut establishment. Identifying such parameters now is especially important for chestnut as it was killed by the blight before wild populations were analyzed using modern ecological methods (Paillet 2002).

This study will focus on a plantation of chestnut on reclaimed mine land in Carroll County, Ohio. Within the plantation, trees that were planted at the same time, in the same healthy condition, have exhibited dramatic differences in survival and growth. This study aims to determine if soil factors, slope, and aspect can significantly account for the observed differences.

RECENT WORK AND JUSTIFICATION

In 1998, The American Chestnut Foundation funded a research proposal by Dr. Gregory Miller of Empire Chestnut Company to examine field establishment of American chestnut seedlings. Eight hundred and ninety-six pure American chestnut seedlings, grown by Empire Chestnut Company, were planted on a moderate slope and ridge in southwest Carroll County, OH that had been strip mined by Regal Mining Company and reclaimed four years prior. Before mining, the site had been a forest that had American chestnut. The site was graded, topsoiled, limed, fertilized, and seeded with grasses and legumes using standard reclamation procedures (Miller 1998). The “topsoil” was a sandy loam mixed with sandstone and shale, described as, "… rough, compacted, and difficult to shovel". Holes were dug with an auger and trees were hand-planted two meters apart with sixty-four trees per row, in a square pattern with fourteen rows that were each eight meters apart. The study also analyzed the use of fertilizers and deer repellent in promoting successful establishment; however, neither had observed impacts on tree survival and growth. In the second year of the study, 120 trees of the same age were planted to replace those that had died. However, in subsequent years at least half of these replacements died as well (Miller 2001). Twelve years later some trees are dead, some have grown little, and some are relatively large and healthy. In retrospect, soil conditions are thought to be the significant influence on survival and growth. In my study, which began nine years after the original study was completed, I examined the soils, slope, and aspect of the planted trees and related these factors to growth and survival rates. Looking at the correlation of the soil factors, slope, and aspect with tree survival and health, it is possible to determine the soil and site parameters are that are critical to the establishment of chestnut.

METHODS

Sample Design

One hundred and forty trees were selected in a grid pattern, marking the first of every eight trees for every row, resulting in 10 by 14 sampling units examined out of the 64 by 14 tree plantation. Each sampling unit was named by a letter-number combination, with letters A-N representing each column in the grid and numbers 1-10 representing each row. A sampling unit consisted of a tree (living or dead). Each sampling unit was marked with flagging in the field and marked on a map. Aspect was measured at each sampling unit using a compass. Percent slope was calculated at each sampling unit by placing one end of a 48 inch plank level at the base of the tree, measuring the vertical distance between the other end and the ground downhill of the tree, and dividing the vertical measurement by the horizontal one.

Soil Sampling and Analyses

Soil sampling was conducted in April 2010. At each sampling unit, a standard 18-in soil probe was used to take three soil core samples in a triangular pattern with each point about 18 inches from the base of each tree or depression where a tree did not survive. These three samples were composited for each sampling unit. A visual description of the soil samples for each unit included color and types of coarse fragments. Descriptions were determined according to the National Resource Conservation Service (NRCS) Field Book for Describing and Sampling Soils (Shoeneberger et al. 2002).

Subsequent laboratory measurement of pH was conducted per sample from a depth of 25 cm according to the NCRS Soil Quality Test Kit Guide (Doran et al. 1999). Soil texture was determined using the hydrometer method to determine the percentages of sand, silt, and clay and classified according to the soil texture triangle (Sheldrick and Wang 1993). Bulk density and relative moisture were calculated from soil samples taken with a bulb planter at each sampling unit on an early spring day just after thaw. Relative moisture was determined by weighing each sample wet, drying and weighing again, and calculating percent moisture from dry weight divided by wet weight. Bulk density was calculated by dividing the mass of each dried sample by the volume from the bulb planter.

Tree Sampling

Tree sampling was conducted in August 2010, following the end of the growing season. The survival of each tree (sampling unit) was recorded. For surviving trees, the cross-sectional area just above the root collar was calculated after measuring the diameter of each stem with calipers, and areas were composited if there were multiple stems per sampling unit.

Statistical Analyses

Statistical analyses included analysis of variance and linear regression using Minitab general modeling procedures. Slope, aspect, and each soil parameter except pH were treated as independent, continuous variables (Table 1). The protocol of Beers et al. 1966, was used to transform aspect from azimuth degrees to a continuous variable. Each tree parameter was treated as a dependent variable; survival being a discreet, binomial variable, and stem cross-sectional area being a continuous variable. Linear regression was used to separately analyze the effects of slope, aspect, percent sand, percent clay, bulk density, and percent moisture on cross-sectional area. Analysis of variance was used to separately analyze effects of slope, aspect, percent sand, percent clay, bulk density, percent moisture, and pH on tree survival. In all cases both degree of correlation and significance were observed.

RESULTS AND DISCUSSION

This study site had a wide range of conditions (Table 1). Variables with the most diversity were slope, pH, and percent soil moisture. Slope ranged from 0-33%, pH from 4.9-9, soil moisture from 13-29%, and bulk density from 1.1-1.68 g/cm^3. Aspect and soil texture were fairly consistent throughout, with aspect mainly east and soil textures in the classes of loam and sandy loam. Of the sampled trees, eighty-one were dead and fifty were alive. Of those living sampling units, the cross-sectional areas ranged from 3.14-211.13 cm^2.

There was a statistically significant effect of slope on both cross-sectional area and survival (Table 2), with a positive linear relationship between slope percent and tree cross-sectional area (Figure 1). No trees survived on slopes less than 6%, and the largest individuals were found on slopes greater than 15% (Figure 2). This appears to be more of a threshold effect than a continuous effect, however, as survival and growth do not necessarily increase as slope increases past 15% (Figure 3).

Percent soil moisture was also significantly related to both cross-sectional area and survival (Table 2), with a negative linear relationship between percent moisture and cross-sectional area (Figure 4). Even though percent moisture is in constant flux depending on recent rainfall minus drainage and evapotranspiration, the effects demonstrated here are noteworthy. In fact, the effect of slope could be interpreted as being derived from its indirect effect on soil moisture (Figure 5).

There was also a significant effect of pH on tree survival (Table 2). A wide range of pH was measured, and there was no survival at pH values greater than 6.6 (Figure 6). Less than 50% of trees survived from pH ranging 5.5-6.6. Slightly more than 50% survived from pH ranging 4.9-5.5.

Percent sand and percent clay were both somewhat related to tree survival and cross-sectional area (Table 2). With tree cross-sectional area, there was a small positive linear relationship with percent sand and a small negative linear relationship with percent clay. It is noteworthy that there was little variation in soil textural class (Figure 8), with all samples falling into the classes of loam or sandy loam, so perhaps the effects of percent sand and percent clay would be more pronounced over a wider range of soil textures.

There were no significant relationships between either aspect or bulk density and tree cross-sectional area and survival (Table 2). There was a small range of aspects across the study area (Figure 7). Bulk density was difficult to measure precisely due to the presence of large fragments and large roots. It is also likely that bulk density varies abruptly across the plot area due to the reclamation process.

Summary of Live Samples

Variable values were averaged and compared between the ten largest and the ten smallest living trees to see if any noticeable differences might account for the variation in growth (Figure 9). There appears to be very little difference in relative values between the groups, especially when comparing the averages. It is likely that while these measured variables may be useful for determining site suitability for chestnut survival, they are not adequate predictors of chestnut growth.

CONCLUSIONS

This previously surface-mined site has a range of soil conditions, slope and aspect, and those conditions had a substantial effect of the survival and growth of American chestnut seedlings planted there. However, the interpretations of results are limited by the fact that this particular site did not include the range of site characteristics encountered across all surface-mined sites. Generally, the site characteristics which showed greater variation are the ones that had the most significant effects. Conversely, the site characteristics which showed little variation appeared to have little effect.

Aspect, percent sand, and percent clay probably were not correlated with growth or with survival because these variables were fairly constant over the site. Because there were trees surviving within these conditions, it may be assumed that the eastern aspect and loam/sandy loam soil textures found within this site are acceptable for chestnut. Due to the observed sensitivity of chestnut to high moisture conditions, it is expected that heavier soil textures would have negative impacts on survival and growth.

Even though soil bulk density was variable, it seemed to have little effect on chestnut tree performance. The lack of an effect might be attributable to technical difficulties in measurement and the likelihood that bulk density might change over short distances. The post-mining reclamation of this particular site was done without the thorough grading of the soil that was standard in other reclamation sites of the time (Miller 2009). Therefore, both bulk density and soil compaction might have more substantial effects on other reclaimed mine sites that experienced more bulldozer traffic. Soil compaction was to be analyzed in this study, but in a twelve-year-old stand of trees, it is difficult to determine whether the soil compaction influenced the tree growth or the tree growth influenced the soil compaction. Compaction data from before the trees were planted would be more useful.

Based on this study, the following inferences can be drawn that are applicable to reclaimed minelands in eastern Ohio. First, chestnut does not survive at soil pH values in the neutral or alkaline range and can be expected to have lower survival rates at slightly acidic pH values. Greatest survival occurs at pH values less than 5.5. This site did not have any pH values less than 4.9, so the effects of low pH values were not measured. Second, chestnut does not tolerate wet soil conditions and survives best on well-drained sites. Third, the variation in survival of chestnut can be mostly attributed to variation in slope, soil moisture, and pH, but the cause for variation in cross-sectional area is less obvious. Comparison of the ten largest and ten smallest trees shows few differences in site conditions, so it can be assumed that factors beyond the scope of this study, e.g., soil nutrients, tree genetics, or deer browsing, may account for differences in growth.

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Table 1. Range, median, and mean for each variable measured. Summary of all sampling units.

Variable	Range	Median	Mean
Tree Survival	81 dead, 50 alive		
Tree Cross-sectional Area (cm^2) [live trees only]	3.14-211.13	28.5	58.3
Slope (%)	0-33.33	14.6	15.3
Aspect (azimuth°)	0-140	50	54
pH [at 25 cm depth]	4.9-9	5.5	5.85
Sand (%)	33.5-60.4	43.5	43.8
Clay (%)	13.2-26.3	19.4	19.6
Bulk Density (g/cm^3)	1.1-1.68	1.41	1.4
Moisture (%)	13-29	20	21

Table 2. Summary statistics in order of significance based upon linear regression of tree cross-sectional area of live sample and analysis of variance of tree survival.

	Cross-sectional area			*Survival*		
Variable	***β***	R^2	***p***	**df**	***F***	***p***
Slope %	3.26	19.2%	>0.001	1	41.06	>0.001
pH (25 cm depth)	n/a	n/a	n/a	1	22.14	>0.001
% Soil Moisture	-5.07	15.23%	>0.001	1	19.67	>0.001
% Sand	1.36	2.1%	0.044	1	5.17	0.025
% Clay	-2.88	1.89%	0.054	1	4.43	0.037
Bulk Density	-52.85	1.6%	0.08	1	1.34	0.25
Transformed Aspect	5.55	0%	0.351	1	0.18	0.67

Figure 1. Scatter plot of tree cross-sectional area of live samples versus slope percent with regression line.

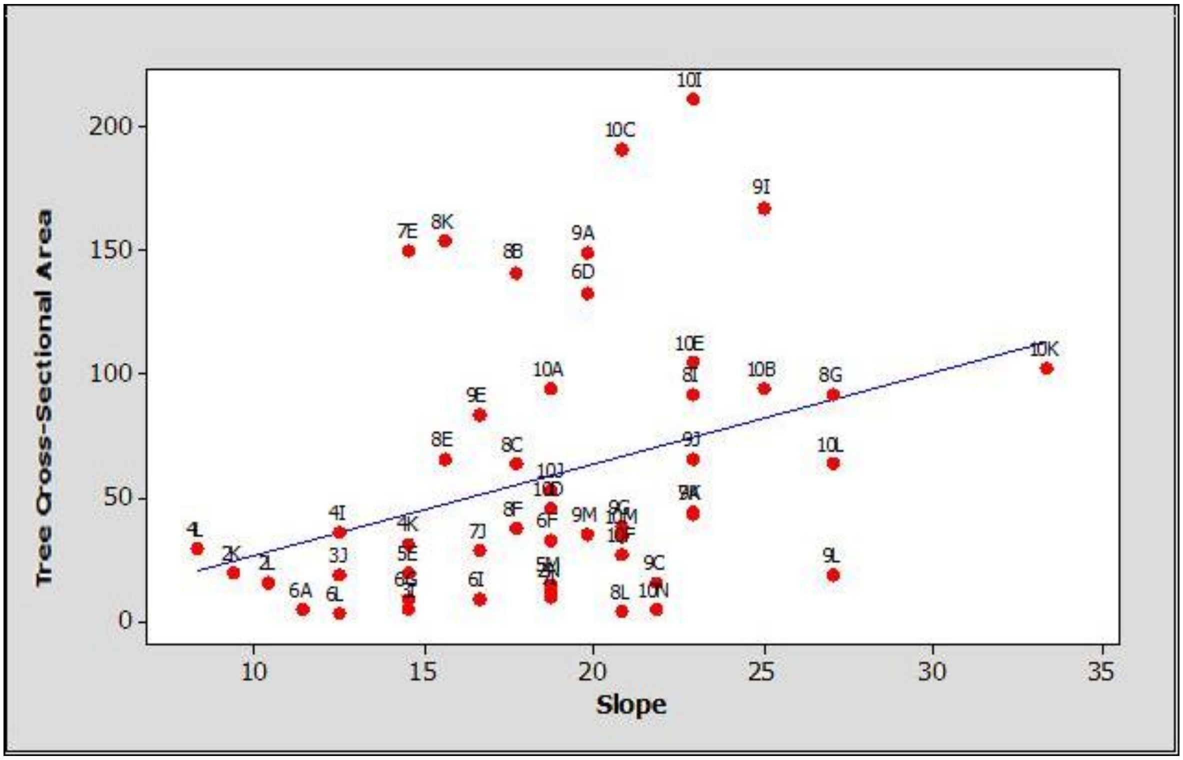

Figure 2. Proportions of live and dead samples by slope class.

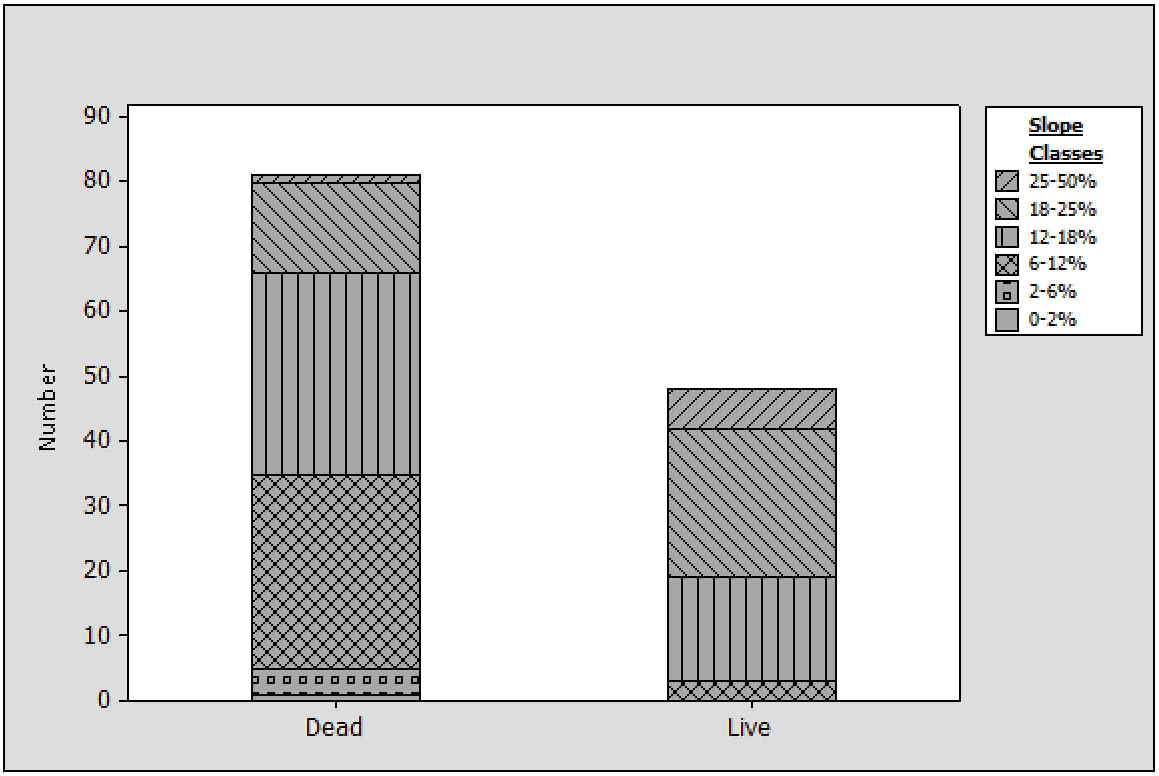

Figure 3. Contour plot of slope. Brown triangles denote live trees and red circles denote dead trees.

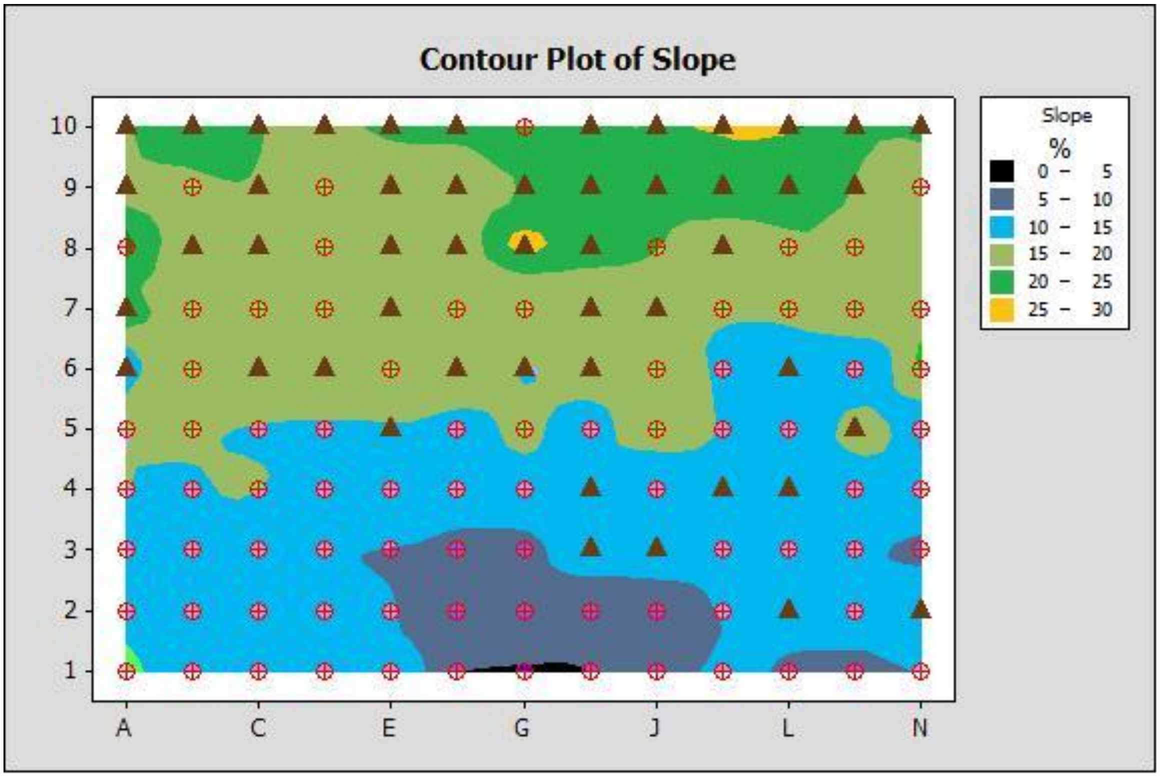

Figure 4. Scatter plot of tree cross-sectional area of live samples versus percent soil moisture with regression line.

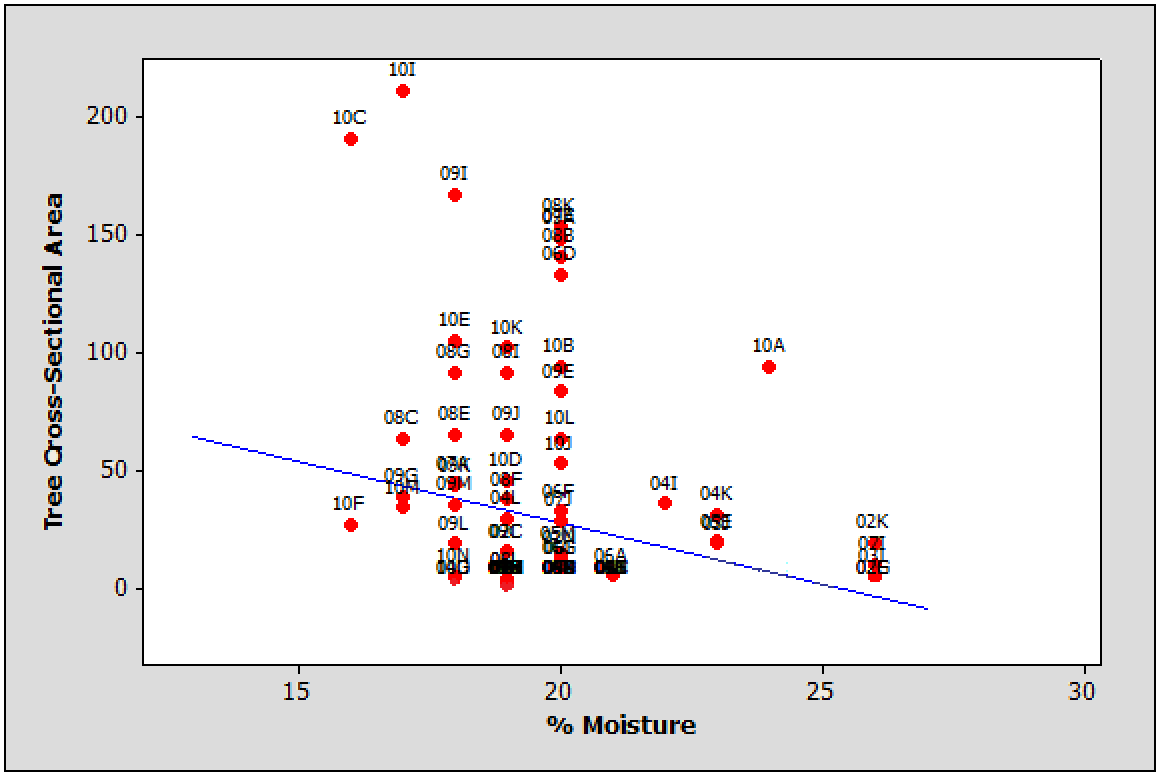

Figure 5. Contour plot of moisture. Brown triangles denote live trees and red circles denote dead trees.

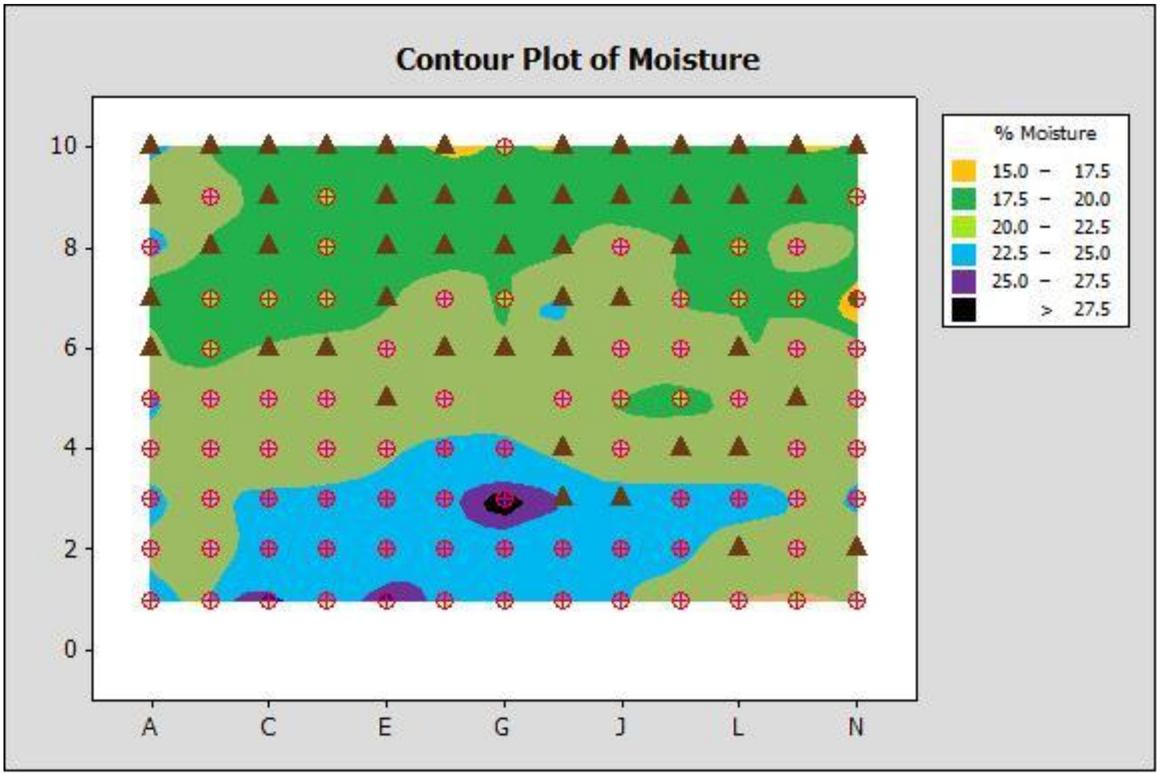

Figure 6. Proportions of live and dead samples by pH class. Classes per Olson (1976).

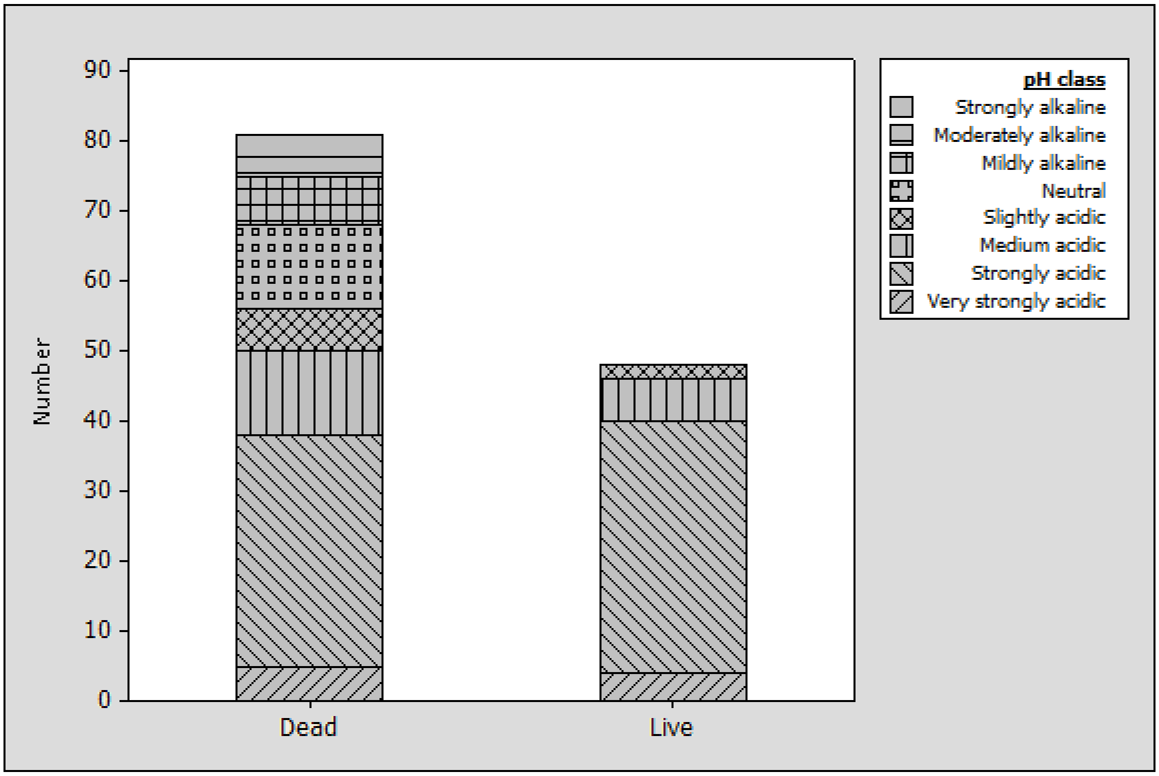

Figure 7. Proportions of live and dead samples by aspect class.

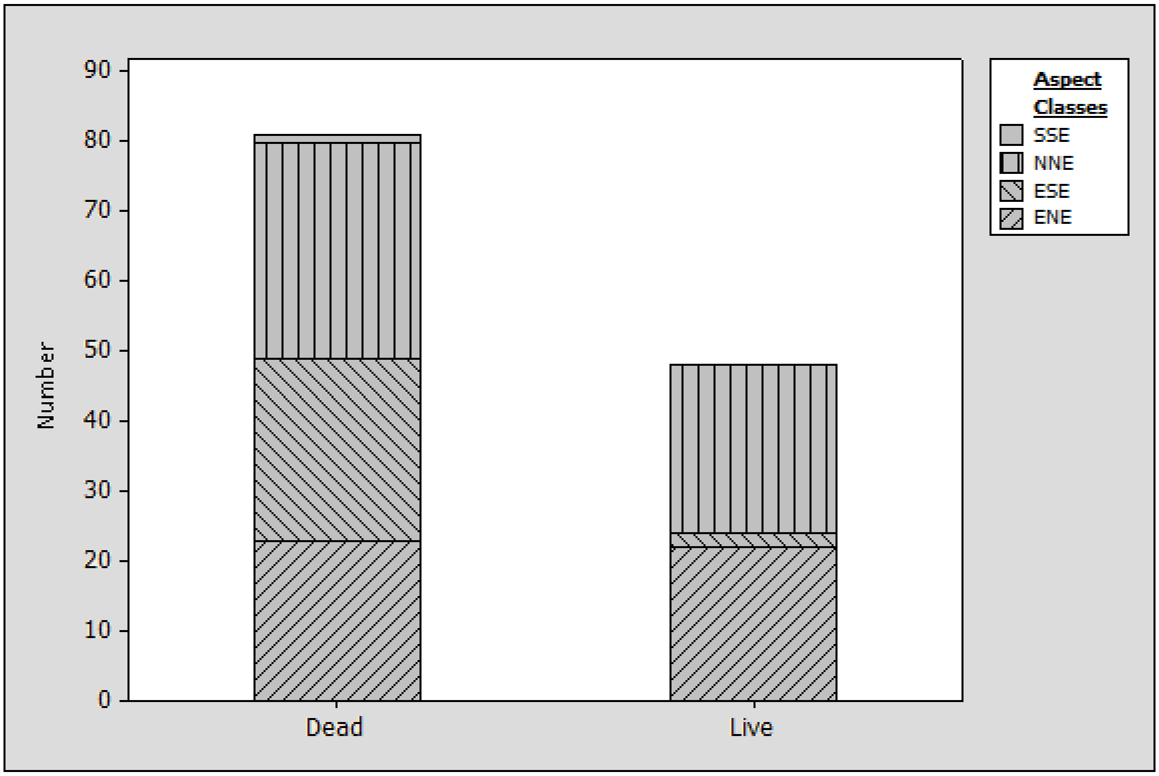

Figure 8. Proportions of live and dead samples by soil textural class.

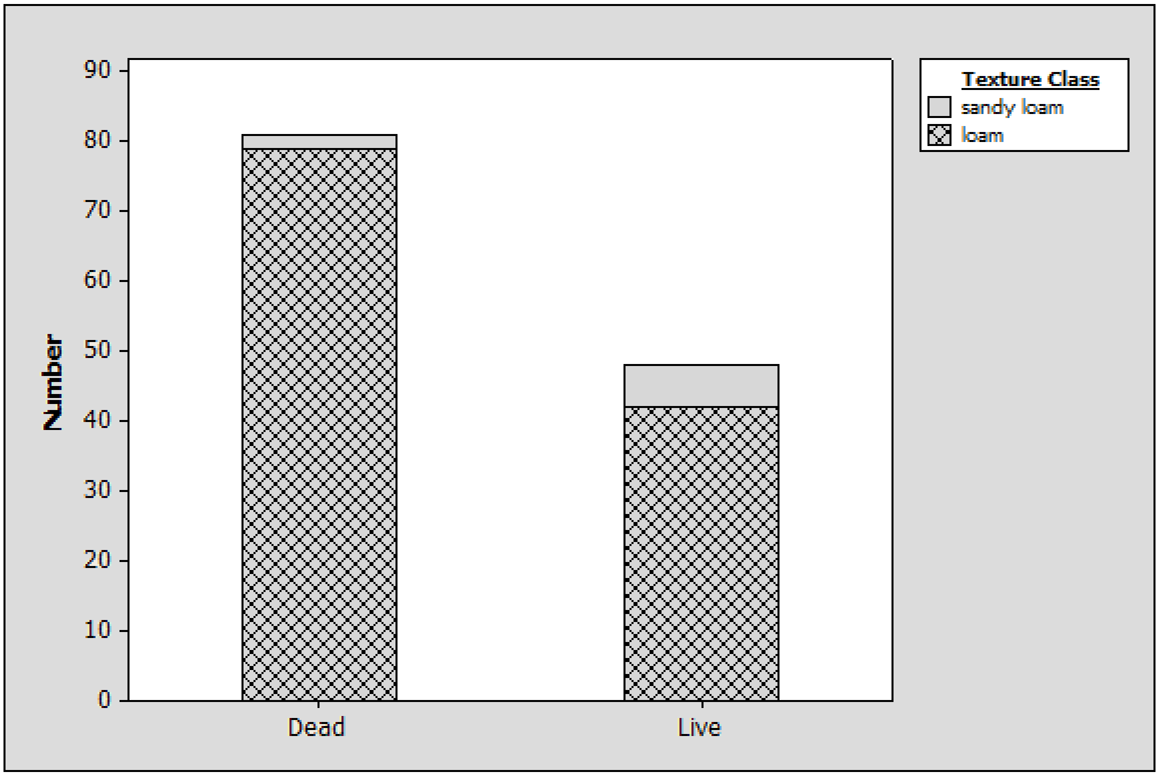

Figure 9. Visual representation of relative values for each variable for each of the 10 largest and 10 smallest live trees. Averages are shown by the bold-colored bars on the right of each group.